The Effect of Depths of Partial Breakwater on Wave Transmissibility by Physical Model

Nantawoot Inseeyong[1,*] and Anurak Sriariyawat[1,2]

[1,2] Department of Water Resource Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand
[2]Research Unit on Technology for Oil Spill and Contamination Management, Chulalongkorn University, Bangkok, Thailand
**Corresponding author; E-mail address: nantawootlt@gmail.com*

Abstract

Coastal erosion in Thailand becomes more dangerous nowadays, especially in the Upper Gulf of Thailand, where is the mudflat. Some kinds of mitigation structures face the subsidence problem because of the lack of the strength capacity of the muddy ground. Therefore, not every type of protection structure can be constructed on this clay. Only the structure that transfers its weight directly and deeply into the ground can initiate in this muddy area. In Khun Samut China village located in Samut Prakan province, the villagers applied the piles with the partial wall on the water surface, as called “partial breakwater”, to protect their land. This kind of structure is an appropriate alternative and has a higher potential for muddy coast protection. However, the effectiveness of the partial breakwater was studied only from the influence of the wave characteristics. The impact of the appearance of the structure is not yet proved. This study aims to investigate the relationship between the physical attributes of the breakwater and the transmission ability of waves through it. The experiment was conducted by varying the depth of the partial breakwater and measuring wave height before and after it hit the structure. After that, the transmission coefficient was calculated. Besides, the influence distance after the structure was considered. The results showed that the more structure depth is, the less wave transmission coefficient becomes. In conclusion, the inverse variation is the tread of the relationship between these two parameters. The results of the study will be usefully revealed to support the design of the mitigation structure for the erosion problem of the muddy coast in the future.

Keywords: Partial Breakwater, wave transmissibility, physical model, wave basin, mudflat

1. Introduction

Coastal erosion, especially in community areas, is a significant concern throughout the world. The issue represents a serious concern for many vulnerable coastlines throughout the coastal regions of the world. This issue must be studied for root causes so it can if at all possible, be brought under some semblance of control before it is too late. The cost of ignoring this issue would be catastrophic to both communities on the beach and the marine life that depend on the coastal areas for their very survival. A breakwater is one of many alternatives to solve this erosion problem by reducing the wave energy that passes through the structure. Due to the difference in ground stability, engineers cannot use every type of breakwater in each area.

Erosion can happen in a variety of places for an assortment of reasons. Some of an eroding coastline are loss of coastal land and a decrease of offshore features. One good example of this is the situation that is happening in the Chao Phraya River delta region. At Chao Phraya River mount, there is both erosion and deposition of sediment. The sediments in this estuary zone are predominantly composed of silt and clay that display substantial distribution in grain size distribution due to hydrodynamic and vegetation cover changes, such as grass, mangroves, and other plantations. However, these muddy shores are very sensitive to erosion [1]. Although many types of breakwaters have been constructed on this muddy ground, almost all of them have faced the subsidence problem due to the weakness of clay, which cannot stand for a heavyweight. As the structure subsided, it lost the performance of the wave energy reduction from the design [2]. Thus, the type of breakwater that suitable for the muddy ground should be the structure that transfers its weight directly and deeply into the ground, not only at the surface.

In Ban Khun Samut Chin Village, Samut Prakarn where has the mudflat along the coastline, the villagers applied the piles with the partial wall in the water surface zone, as called “partial breakwater”, to protect their land. The structures are made from plenty of electricity poles left from the area where the electric wires were managed to be underground, as shown in fig. 1. This structure transfers the wave force from the partial wall, combining with their weight, directly and deeply into the ground by using their columns. Therefore, the partial breakwater may be an appropriate alternative and has a higher potential for muddy coast protection; however, the effectiveness of the partial breakwater was studied only from the influence of the wave characteristics [3]. The impact of the appearance of the structure is not yet proved. Since at present the villagers use a large number of piles to construct the structure and design the shape of breakwater by using their own experience, the design can be under or over the necessary depth leading to the remaining coastline erosion problem or the increase of construction cost.

Fig.1 Partial breakwater at Ban Khun Samut Chin Village

This study aims to investigate the relationship between the physical attributes of the breakwater and the transmission ability of waves through the partial breakwater. The study results will be revealed and usefully adapt to construct the mitigation structure from now on.

2. Wave Theory

2.1 Water wave mechanics

2.1.1. Wave procreation

When the surface of the water’s body is disturbed in the vertical direction, the force of gravity will act to return the surface to its equilibrium position. The returning water surface has inertia that causes it to pass its equilibrium position and establish a surface oscillation. This oscillation disturbs the adjacent water surface, causing the forward propagation of a wave [4]. Accordingly, the wave is a changing up and down of the water surface in each period and position.

A wave on the water surface is thus generated by some disturbing force which may typically result from the wind, a moving vessel, or the gravitational attraction of the sun and moon. These forces impart energy to the wave, which transmits the power across the water surface until it reaches some obstacle such as a structure or the shoreline, which reflects and dissipates the wave energy [4-5].

2.1.2. Definition of wave parameters

Waves are mostly described and measured by seven wave parameters as follows: [4-6]

- Wave height (H) is the difference between the elevations of a crest and an adjacent trough.
- Wave period (T) is the time taken for a wave to pass a point.
- Wave length (L) is the distance from one point on a wave to the same point on the next wave.
- Wave celerity (C) is the distance traveled by a wave in one second.
- Still water level (SWL) is the assumption line that defines the still water level.
- Water depth (d) is the distance from the still water level to the bottom surface.
- Wave steepness is the parameter that determines the stability of the wave defined by:

$$\text{wave steepness} = \frac{H}{L} \qquad (1)$$

Fig. 2 depicts a monochromatic wave traveling at a phase celerity C on the water of depth d. The definition of other parameters will be shown in this figure.

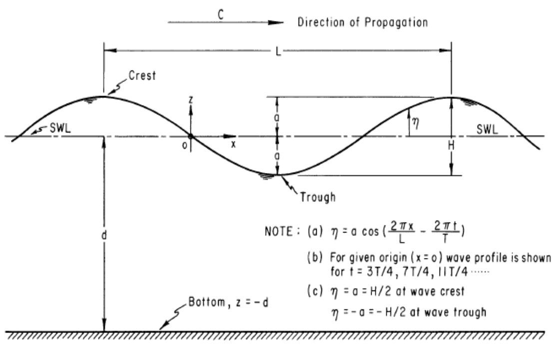


Fig.2 Definition of Wave Parameters [5]

2.2 Small amplitude wave theory

Small amplitude wave theory or Airy wave theory is the theory that has ideas from the ideal flow of liquid in two-dimensional, freely propagating, periodic gravity waves. This theory is developed by linearizing the equations that define the free surface boundary conditions. This theory is generated from a linear equation with the free surface condition. The effects of viscosity or surface tension are regardless. The theory describes the characteristics of the wave as a simple harmonic wave, which is the linear motion of waves [4].

Small-amplitude wave theory is applied by using the equations, as shown in Table 1, to calculate some wave parameters. The equations in this theory are classified by the types of a wave, which are shallow-water-wave, intermediate-water-wave, and deep-water-wave, respectively [5]. The types of waves can be sorted by the ratio of water depth to wave length (d/L), as shown in Table 1.

Table 1 Wave characteristics equations by using Small amplitude wave theory. [5]

Wave Parameter	Shallow water $(\frac{d}{L} < \frac{1}{25})$	Intermediate water $(\frac{1}{25} < \frac{d}{L} < \frac{1}{2})$	Deep water $(\frac{d}{L} > \frac{1}{2})$
Wave Length	$L = T\sqrt{gd}$	$L = \frac{gT^2}{2\pi}\tanh\frac{2\pi d}{L}$	$L = \frac{gT^2}{2\pi}$
Wave celerity	$C = \sqrt{gd}$	$C = \frac{gT}{2\pi}\tanh\frac{2\pi d}{L}$	$C = \frac{gT}{2\pi} = \sqrt{\frac{gL}{2\pi}}$

2.3 Wave transmission coefficient

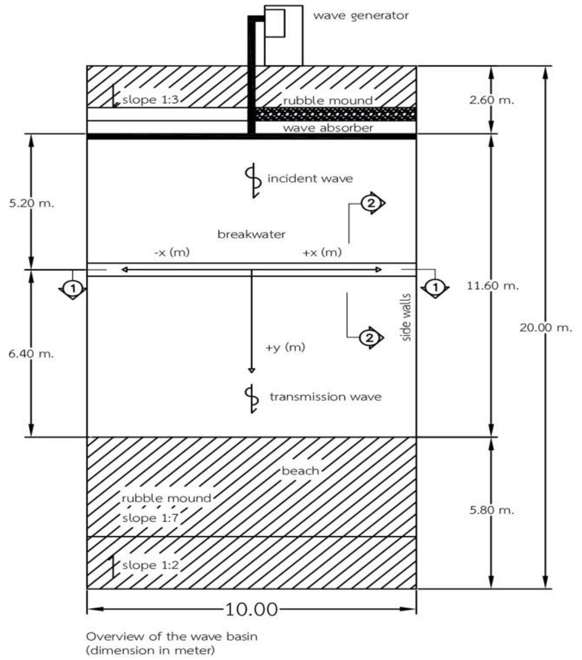
Wave transmission is an ability of waves that can pass through the breakwater structure. Several laboratory investigations were conducted in the past to quantify the transmission coefficient, defined by:

$$K_t = \frac{H_t}{H_i} \qquad (2)$$

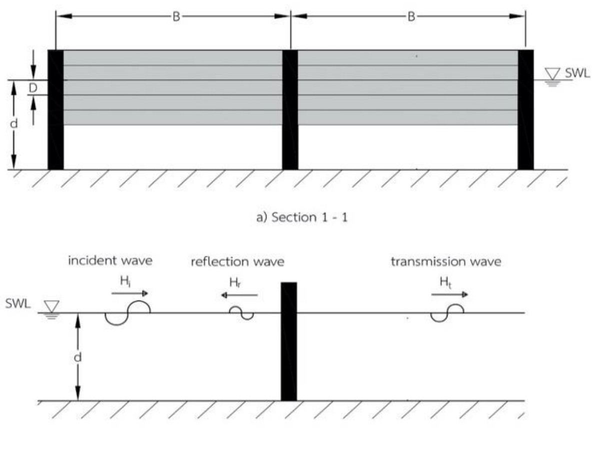
Where, H_t and H_i are the measures of the transmitted waves and incident waves, respectively [7-9]. The value of the transmission coefficient depends on many factors, including the porosity of breakwater, the thickness or the depth of breakwater, and the wave characteristics.

3. Methodology

This study used a two-dimension physical model to observe the wave characteristics that passed through partial breakwater. The experiment was conducted by varying the depth of the partial breakwater and measuring wave height before and after it hit the structure. After that, the transmission coefficient was calculated. The experiments were performed in the rectangular wave basin with 10 meters width, 20 meters length, and 0.7 meters height as shown in fig. 3 and fig. 4. The wave basin has a wave generator with a hinge connection to create the wave in different characteristics. For reducing the wave reflection from the wall, this basin has a rocky beach to absorb the wave energy. The direction of the waves created by the wave generator will be moved along the length of the pool, which is perpendicular to the beach. The depth of water in this experiment is 0.45 meters, and the thickness of the structure is 0.0375 meters.



(a) Drawing of Wave basin



(b) Cross-section of breakwater

Fig.3 Wave basin and location of Breakwater

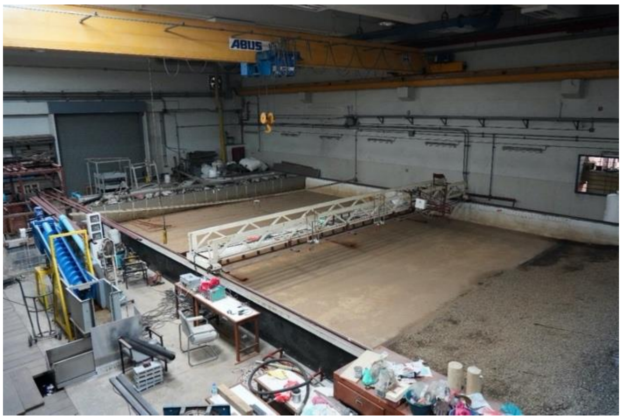
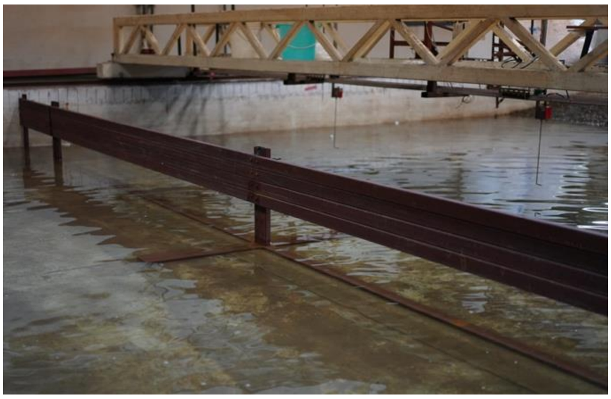


Fig.4 Wave Basin

3.1 Experiment setup

The artificial partial breakwater was constructed in this experiment by using the rectangular carbon steel boxes, which four times scale down from the real structure, as shown in fig. 5 [10]. The structure was located at the center of the wave basin, as shown in fig. 3.



(a) The construction of artificial partial breakwater

(b) The layer of artificial partial breakwater

Fig.5 Artificial Partial Breakwater

This experiment will continuously consider from the previous study [3] by changing the submerged depth of the structure into four values, including 0.075, 0,150, 0.225, and 0.300 meters. Additionally, the structure has some parts located over the still water level, which used to prevent the overflow of the waves by using 0.15 meters height of steel boxes over the still water level, as shown in Fig. 3.

3.2 Data collection

During the experiment, the wave height was measured by using CH-403A and CHT4-40 wave gages from Kennek company. The data was collected in the frequency of 50 wave data per second for 30 seconds per one point. For the transmitted wave, the locations of data collection in x-axis or alongshore direction were -2.50, 0.00 and +2.50 meters, in y-axis or cross-shore direction were 0.10, 0.20, 0.40, 0.60, 1.00, 2.00, 3.00 and 4.00 meters. It was noted that the center of the measuring axis was in the middle of the structure. For the incident wave, the location of data collection was in the middle of the structure in alongshore direction and 2 meters far from the structure in the cross-shore direction, as shown in fig. 6. The wave gauges read the data in the volt unit by using the electrical conductivity method. The wave was generated and created the different water levels that gave different electrical potential depending on the wave configuration. This study calibrated and verified the wave gages by using the observed wave height data from the video camera in a linear regression method. The volt data from wave gauges was converted to a wave height by using these regressions.

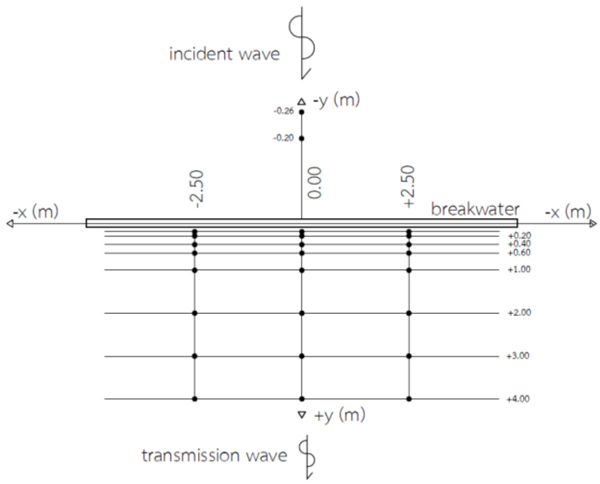


Fig.6 Data Collection's Location

3.3 Parameter consideration

This study fixed a lot of parameters, such as the water level, and the thickness of the structure. Additionally, the wave steepness in the upper gulf of Thailand is about 0.010 – 0.025 [11]. As verified in the previous study [3], this study would vary the wave steepness for five values between 0.010 and 0.025, which are the representatives of wave steepness in the upper gulf of Thailand where is the mudflat. Moreover, the main focus parameter was the submerged depth of the structure. Thus, this experiment would vary for four values of the structure's depth, which was 0.075, 0,150, 0.225, and 0.300 meters.

From the wave collecting instruments, wave height and wave period were measured and calculated. However, equation (1) required the wave length parameter. Accordingly, this study was based on the assumption of small-amplitude wave theory; the wave length could be calculated using Table 1.

In changing the steepness of the incident wave, the wave height before and after it hit the structure was measured. The wave transmission coefficient was calculated after that by using equation (2).

4. Result and Discussion

Due to the duration and the frequency of data collecting, the recorded data from wave gauges consisted of many waves. Therefore, frequency analysis was performed by using the Power Spectral Energy (PSE) method, with a graph of the relationship between the density power and frequency. As a regular wave, the chart had only one peak frequency, and the reversion of peak value was the wave period. The wave height in each wave was calculated by using the wave period. Then, significant wave height was calculated by defining traditionally as the mean wave height of the highest third of the waves.

As the steepness calculation, the wave length was calculated by using small-amplitude wave theory and equation in Table 1. The estimates of the wave classification provided the result that the wave in every experiment was in the range of intermediate water waves. Therefore, the middle equation in Table 1 would be used to calculate the wave length. Then, wave steepness was calculated by using equation (1), and the wave transmission coefficient was calculated by using equation (2).

Firstly, the influence distance from the structure in transmitted direction was considered. fig.7 shows the plotting of the relationship between the location in cross-shore direction and the transmission coefficient. As a result of the difference of wave characteristics, especially for the value of wave length in each case, the dimensionless parameter should be considered to compare for the influent distance. Nevertheless, the wave length is the parameter that has the same direction with the influence range, so that the dimensionless setting would be the ratio of influence distance to wave length (y/L) following the previous study [13]. From fig.7, the graphs do not compare only the relation from W1 to W5 and also D1 to D4, which refers to the large to the small value of incident wave steepness and submerged depth, respectively.

The result from graphs in fig.7 shown that the distribution of the transmission coefficient from the cases that have the same submerged depth was quite similar. On the contrary, the distribution from the evidence that has the same incident wave steepness was different. It means that the incident wave steepness will have more effect on the influence distance than the submerged depth of the structure. Moreover, there was a turbulent effect after the wave passes through the breakwater, which can see from the jerk of the transmission coefficient next to the structure, which had some relationships with the incident wave steepness. The peak of the turbulent was located at the center of the turbulent distance. After that violent location, the value of the transmission coefficient would be stable for some distance in the cross-shore direction. However, some cases would have an increase of the transmission coefficient at far away from the structure. These events show that partial breakwater can reduce the wave energy or wave height for an only limit interval, which has the relation with the incident wave steepness[14]. Although only in case W1 and W2 can obviously see the limit of influence distance, the effects in W3, W4, and W5 are not able to see because of the size of the wave basin. The summary of the results shows in Table 2.

Table 2 Influence distance from the partial breakwater

Wave Parameter	Wave Characteristic				
	W1	W2	W3	W4	W5
Wave Steepness	0.010-0.013	0.013-0.016	0.016-0.019	0.019-0.022	0.022-0.025
Wave Length (m)	3.117	2.555	2.120	2.120	2.120
Turbulent distance (y/L)	0.65	0.60	0.50	0.50	0.50
Influence distance (y/L)	1.00	1.20	~	~	~

Remark : ~ refers that the influence distance is larger than the boundary of wave basin

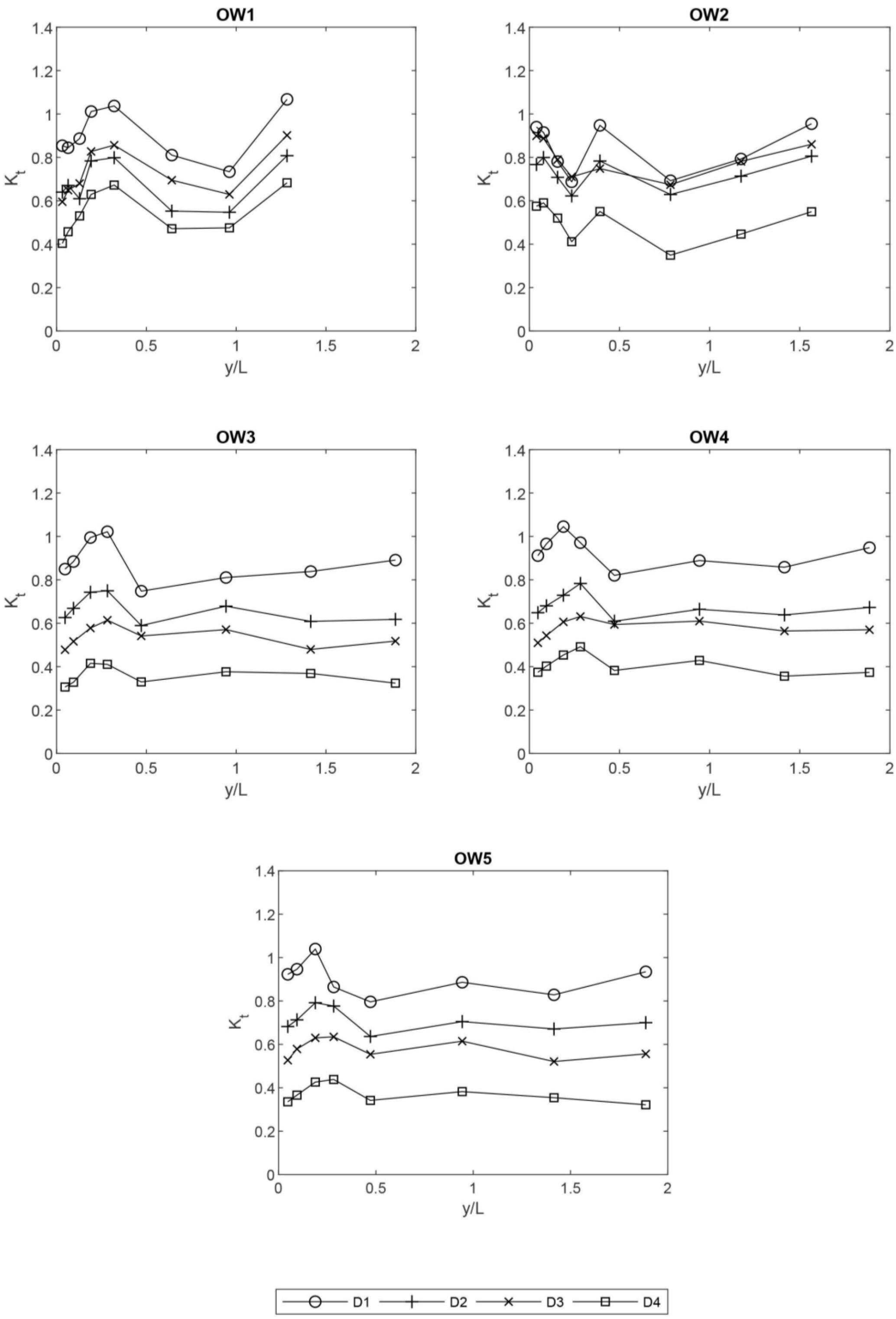


Fig.7 The wave transmission coefficient and the ratio of distance in cross-shore direction to wave length (y/L)

Table 2 and fig.7 show that the more wave steepness leads to be the less turbulent distance and the more influence interval. For deep consideration, the trend of the turbulent distance and the influence distance may depend on the wave length. Owing to W3 – W5 has the equal wave length with less than W2 and W1, respectively, and they give the result of the turbulent distance as the same trend and the influence distance as the opposite trend, with the same values. So wave length may be the significant parameter that affects the wave dissipate. From the small-amplitude wave theory, the more wave length is, the deeper of wave energy distribute [15]. Therefore, the deeper of wave energy can go through under the structure and make the turbulent distance long and the influence distance short. However, this study has the boundary that the length of the wave basin was limited, so the effect from the wave length should be proved in future research.

Secondly, many points of measuring at the transmitted front of the structure occurred in each case. So, the considering of the symbolic value of the transmission coefficient was essential. For alongshore direction, the average of three points, which are -2.5, 0, and 2.5 meters, were used as the exponent of each layer. Combine with the distribution in fig.7, there was a turbulent effect at 10 to 100 centimeters, far from structure. Moreover, some cases would have an increase of the transmission coefficient at layer 400 centimeters, far from structure. Normally, the value of the transmission coefficient was stable at 200 and 300 centimeters, far from the structure. So, the result values at 200 and 300 centimeters, far from the structure, which were the most suitable location, would be averaged as a representative value of the transmission coefficient in each case.

As a result of wave transmission which showed in Table 3, the trends of the relationship between wave transmission coefficient and the submerged depth of the structure could be plotted, as shown in fig. 8. It shows that the increase of the submerged depth leads to the decreasing of wave transmission coefficient. The reason for this correlation is energy dissipation from the submerged bottom of the partial breakwater. Waves that dynamic on the water surface will not only have energy in the water surface zone but also deeply expand their power through the water depth [4-6]. Therefore, if the breakwater is deeply constructed, it will dissipate the wave energy not only at the water surface but also on a more in-depth level. Accordingly, the deeper the submerge depth is, the more wave energy dissipates, and the decreasing of wave transmission coefficient becomes.

Table 3 Transmission coefficients

Incident Wave Steepness	Transmission Coefficients (K_t)			
	D1 (0.075 m.)	D2 (0.150 m.)	D3 (0.225 m.)	D4 (0.300 m.)
0.010 – 0.013	0.89	0.88	0.72	0.60
0.013 – 0.016	0.89	0.84	0.62	0.56
0.016 – 0.019	0.77	0.76	0.56	0.35
0.019 – 0.022	0.78	0.74	0.56	0.35
0.022 – 0.025	0.78	0.75	0.56	0.34

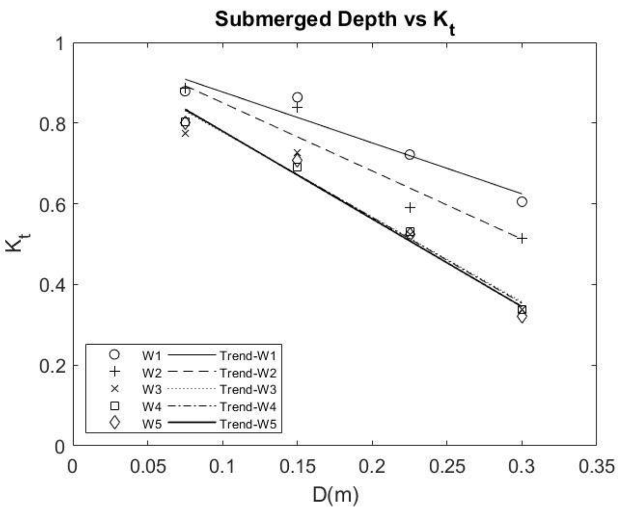


Fig.8 Relation of wave transmission coefficient and submerged depth

To verify the study in the past, fig.8 compared the relation from W1 to W5, which refers to the incident wave steepness that sorted from small to big. It shows that the higher the incident wave steepness through the partial breakwater is, the lower the wave transmission would become. This result was following the previous study [12]. Combine with the influence of submerged depth, the graph shows that the slope of the regression in large incident wave steepness is steeper than in small ones. It could conclude that the influence of the submerged depth to the transmission behavior will have more effect in larger incident wave steepness than in smaller ones.

Consequently, this study can be concluded that the more increasing of incident wave steepness through the partial breakwater is, the more decreasing of wave transmission and influence distance would become. The more submerged depth of the structure is, the more decreasing wave transmission would grow as well.

5. Conclusions

Due to most of the coast in the upper gulf of Thailand is the mudflat, some types of breakwater may not function as the design in this muddy area. Therefore, the engineers need to design the structure that suitable for this muddy ground. Partial breakwater or the piles with the partial wall on the water surface is one of the alternatives to solve this problem.

This paper presents the wave transmission through the partial breakwater with the varying of the submerged depth of the breakwater and incident wave steepness by using a one-dimension physical model in flat bed wave basin. Wave height before and after it hit the structure was measured. After that, the transmission coefficient was calculated in each case. The relationship of transmission coefficient and submerged depth in each incident wave steepness were shown in fig.8.

As the results of transmission coefficient in this study, the submerged depth of partial breakwater would affect the transmission behavior of waves through the structure. The results show that the more profound the submerge depth is, the more wave energy dissipates or the wave transmission coefficient decreases. Moreover, the incident wave steepness that moved through the breakwater affected the transmission of waves through the gap in the breakwater as well. Follow the previous study, these results can conclude that the higher of the incident wave steepness through the partial breakwater is, the lower the wave transmission would become. Additionally, the higher the incident wave steepness will affect the distance that the structure will have an influence by the more decreasing influence distance would grow and the more decreasing turbulent distance would become.

This study has some limitations from the experimental instruments that make this study base on the assumptions. However, using the results in the real area may be out of the assumptions, so it is necessary to study more especially about the variable of water depth, the length of the breakwater, the width of the breakwater, the distance between column, and the porosity of the structure to design the structure that is suitable for the actual environment.

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